International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 9, Issue 3, Jun 2019, 1363-1370

EXPERIMENTAL INVESTIGATION OF WEAR BEHAVIOUR ON SINTERED TI6AL4V/YTTRIUM OXIDE NANO-COMPOSITE

R. RAMASWAMY[1,2], P. MARIMUTHU[3] & B. SELVAM[4]

[1]*Department of Mechanical Engineering, Bharath Institute of Higher Education and Research, Chennai, Tamil Nadu, India*

[2]*Assistant Professor, Department of Mechanical Engineering, MNM Jain Engineering College, Chennai, Tamil Nadu, India*

[3]*Department of Mechanical Engineering, Karaikudi Institute of Technology and Karaikudi Institute of Management, Karaikudi, Tamil Nadu, India*

[4]*School of Mechanical and Industrial Engineering, Ethiopian Institute of Technology-Mekelle, Mekelle University, Ethiopia*

ABSTRACT

Wear behavior of yttrium oxide reinforced titanium alloy (Ti6Al4V) was studied under the dry sliding condition at room temperature. Wear is the major drawback for the modern components made with titanium alloy to the advanced applications. Wear rate was determined by considering the sliding distance, sliding velocity and applied load by using pin-on-disc. The composite pin surface was sliding against the oil hardened non-shrink (OHNS) steel surface at the velocity range between 0.6 to 1.2 m/s for sliding distance of 1600m by varying the load from 5 to 10N. Wear rate is changing directly proportional to the applied load and sliding velocity. The composite having 2%.wt. of yttrium oxide reinforced shows better wear resistance as compared to the 1 and 3%.wt.of reinforcement.

***KEYWORDS:** Wear Rate, Composite, Titanium, Sliding Velocity & Sliding Distance*

Received: May 02, 2019; **Accepted**: May 22, 2019; **Published**: Jun 03, 2019; **Paper Id**.: IJMPERDJUN2019142

INTRODUCTION

Metals/alloys such as aluminum and magnesium are mostly used for various applications, which have lower density alloys. But Titanium alloys are having unique properties such as high temperature strength, high strength to weight ratio that is used for excellent resistance for heat and corrosion. These alloys are having better hardness than magnesium and aluminum alloys. The metal matrix composite is the most vital area for the research in the aspect of advanced engineering components performance enhancement. The metal industries are having huge scope for the specific applications. Titanium provides extremely higher properties as compared with other non-ferrous metals to the high affinity behavior of titanium alloy with oxygen; it provides solid lubricant (titanium oxides) against the sliding surface [1]. However, these alloys have certain limitations in the properties such as low wear resistance due to the action of sticking at junctions of the contacting surfaces during sliding [2-6]. This major disadvantage of titanium alloy may be eliminated and working surfaces must be protected against wear. So, many researchers used many methods to improve the wear resistance of two-phase titanium alloys [7].

Original Article

Frary et al [8] fabricated a composite of tungsten reinforced in the Ti6Al4V matrix through powder metallurgy and proved that the improved mechanical properties of strength and hardness by losing minimum ductility.

Titanium alloy (Ti-6Al-4V) is extensively used in various applications such as aerospace, medical, marine automotive and industrial components. It is an advanced material due to excellent mechanical and physical properties. Several works makes substantial consideration to determine the influence of roughness on the tribological behavior of two materials contacting, while sliding against each other. For instance, hard particles are reinforced in the matrix of alloy to determine the optimum abrasive particle size with respect to the optimal roughness with minimizing the friction and the wear rate [9-12]

Wear is the loss of metal in terms of powders from its surface, while sliding with another surface. It is the major requirement for the most of the metals/alloys for withstanding longer period. This behavior is not able to completely avoid, but it can be minimized through various techniques. The most economical method to improve the wear resistance technique is called as composite method [13]. The wear property can be enhanced through reinforcing the hard particles in the matrix of metals/alloys. The wear rate is to be determined with respect to the amount of reinforcement. The influence of hard particle amount has to be predicted for improving the wear property [14-16]. In this study, the Ti6Al4V alloy matrix reinforced with yttrium oxide (Y_2O_3) nano-composite was studied. The dry sliding wear behavior is new effort in the aspect enhancing wear behavior.

MATERIALS AND METHODS

Ti6Al4V powder having particle size of 325 meshes was used as matrix material and yttrium Oxide (Y_2O_3) particle having 40 nm particle size of 99.995% purity was used as hard piece reinforcement. Nano-composite of Ti6Al4V/Y_2O_3 was fabricated by using these powders through powder metallurgy method. Ti6Al4V/ Y_2O_3 composite with the higher densification of 3.9 g/cm^3 and 87.69% of relative density achieved in Ti6Al4V/ 2% wtY_2O_3 was used for wear analysis. The chemical elements of Ti6Al4V and Y_2O_3 metal powder were given in the earlier paper [17].

NANO-COMPOSITE FABRICATION

Composite materials are manufactured through different techniques such as solid state processing and liquid state processing. Liquid state processing method is used at high temperature and Ti6Al4V is more unstable at high temperature which will be highly affected by nitrogen, hydrogen and oxygen. The controlling of operational atmosphere is more vital for casting processes of Ti6Al4V composite. Powder metallurgy processing techniques is the most suitable and cheapest way for titanium composite fabrication. The powder metallurgy techniques are used for fabricating landing gears and aerospace engine components, which provides shock resistance with reduction of weight [18, 19] .

The powder metallurgy technique was used to fabricate nano-composites of Ti6Al4V/Y_2O_3 and Ti6Al4V preforms. Blending, cold compaction and sintering processes have been followed for fabricating composites and titanium alloy. Ti6Al4V and Y_2O_3 powders were mixed for uniform distribution of both particles by using mechanical ball mill for the period of 1 hour. The main objective of blending is to distribute the reinforcement particles in the matrix phase to avoid the heterogeneous effects in the structure of nano-composites. The cold compaction was executed to consolidate the mixed powders into green preforms. The required amount of mixed powder was put into the female punch and male die were operated from the top for powder compaction. The pressure of 560 Mpa was gradually applied through the punch with a help of 100 ton hydraulic press. The external surfaces of punch and internal surfaces of die were applied molybdenum di-

sulphide to provide as lubricant since during the compaction process leads to produce heat. This lubricant was mainly applied to eject the green compacts easily from the die surface.

The compacted green performs were required to further strengthen for removing porosity through sintering. The electric arc furnace sintering process was done at the temperatures of 1200, 1300 and 1400^{o}C for the period of 2 hours. The controlled atmosphere was used for sintering in order to restrict reactions of composite with nitrogen, hydrogen and oxygen.

PREPARATION OF PIN AND DISC

The preparation of wear test sample and disc is very important for the getting the accurate wear rate data. Sintered nano-composite of Ti6Al4V/Y_2O_3 samples was machined from diameter of 3 mm to 10 mm, for the length of 15 mm. The pin ends were machined and removed the burrs and sharp corners, which could protect the disc surface during sliding. SiC paper having 600-grit was used for grinding the contact surface of the composite pins and OHNS discs to produce smooth surface and then these surfaces cleaned by using acetone. The flatness and perpendicular positioning of the sintered nano-composite pin surfaces were verified for confirming to make perfect contact while sliding.

WEAR TEST

The wear test was conducted under the room temperature and dry sliding condition in a pin-on-disc wear-testing machine. The machine used for the wear test is shown in Figure 1. Table 1 shows the specification of pin on disc machine used for the study. Sintered nano-composite pin samples were held in the wear testing machine slot which was above the rotating disc. The surfaces of both sample bottom and disc top was retained at 100% contact. Before fixing the pin, it was measured and noted. The sensitive electronic balance with an accuracy of ±0.1 mg was used to determine the mass. The experiments were accompanied at applied loads of 5 N, 7.5 N and 10 N for sliding velocities of 0.6 m/s, 0.9 m/s and 1.2 m/s[20]. The mass of the pin was accurately measured after the test conducted which was done by removing the wear debris on the pin surface.

Figure 1: Front and Top View of Pin-on-Disc Wear-Testing Machine

Table 1: Specification of Pin-on-Disc Wear-Testing Machine

Details	Range
Diameter of the specimen pin	3 mm -12 mm
Speed range	100 rpm – 2000 rpm
Track radius distance	0 mm – 70 mm
Load	5 N- 40 N

These mass losses were calculated at every sliding velocity and loads that is each combination of normal load and sliding distance velocity. Before wear test of each pin, the disc contact surface was carefully checked to remove unwanted particles on the sliding surface which was ground with 600-grit SiC paper. Finally, acetone was used to clean for removing the accumulated particles on the disc surface. The experiments were repeated thrice to confirm the possible experimental error.

RESULTS AND DISCUSSIONS

The wear rate of the Ti6Al4V alloy and nano-composite were determined at different sliding velocities (0.6 to 1.2 m/s) and applied loads of 5-10N. The wear rate of the unreinforced alloy is more as compared to all the nano-composites reinforced with 1-3% of yttrium oxide. The wear rate of the 2%.wt. yttrium oxide reinforced nano-composites was dominating the more wear resistance than other composites.

The higher wear rate was observed during the lower sliding velocity at 0.6 m/s of composite irrespective of reinforcement amounts under the higher applied load at 10 N. During the lowest sliding velocities, counter face exerted an abrasive effect on the Ti–6Al–4V and composite, therefore accelerating oxidative wear created at this stage. But the wear rate decreases with increasing sliding velocitydue to oxidation of the surface taking place since more frictional forces offered in the contacting surfaces. So, the increase in surface temperature accelerates and produce oxidizing layer in the composite and alloy surfaces as protection layer against the wear.

At the higher sliding velocity (1.2 m/s), delamination mechanism was observed. Pin was sliding at low velocity (0.6 m/s), micro-cracks were found on the worn surface due to lower temperature, but these micro-cracks were not found at the higher sliding velocities (0.9-1.2 m/s). The micro-cracks were observed in the worn surface perpendicular to the sliding direction of the pin over the disc and these micro-cracks propagated into shear at the later stage of sliding. The magnitude of micro-cracks was less in the nano-composite of 2%.wt.yittrium oxide reinforced as compared to unreinforced alloy.

The specific wear rate decreases with respect to the reinforcement addition in the matrix phase due to the presence of hard particles hardness of the surface increases. The wear experiment was clearly shown that the wear rate decreases from 1-2%.wt.yttiurm oxide, but it reverse action taken from 2 -3%.wt.yttrium oxide reinforced composite.

Wear rate of the alloy and composites were initially less at low load (5 N) but wear rate increases when applied load varies from 7.5 to 10N with respect to the all the sliding velocities. The rate of change of wear abruptly increased when the load increases at the higher loads and higher velocities. This phenomenon happened due to the higher frictional heating rate at higher velocity and applied load. Further, the poor thermal conductivity of the titanium alloy and hard reinforcement particles also considered as factor to increases the frictional coefficient.

The wear rate increases with increasing sliding distance in all sliding velocities under the various applied load. The rate of change of wear rate was more up to sliding distance of 500 m and change of wear gradually decreases after the

sliding distance of 500 m and the same trend observed upto the maximum sliding distance of 1600 m. This is due to the sticking of pin and counter surfaces and lower thermal conductivity.

The frictional coefficient of alloy and composites were observed during the sliding with respect to the applied load and velocities. The coefficient values were initially fluctuated rather than constant due to the various parameters. The higher frictional coefficient values were observed at the low load under the lower sliding velocity (0.6m/s). But the coefficient values decreases for the sliding velocity from 0.6 to 0.9 m/s and again coefficient values increased for the sliding velocity from 0.9 to 1.2 m/s. These trends were observed due to the localized fracture of soft matrix at lower and higher velocities. Earlier researcher [21] published the same result for the ceramic and polymer materials.

CONCLUSIONS

The dry sliding wear and frictional behavior of Ti6Al4V and Ti6Al4V/Y_2O3 were observed at the various parameters such as 0.6 to 1.2 m/s sliding velocities and 5 to 10 N applied load under the room temperature condition. The following remarkable conclusions are made:

- The lower wear rate was observed at the 2%.wt.yttrium oxide reinforced composites as compared to unreinforced alloy and 1 and 3%.wt. yttrium oxide composites.
- The higher wear rate produced during the lower sliding velocities and higher applied load irrespective samples of composition.
- The decreased wear rate was observed during the condition of higher sliding velocities and lower applied loads.
- The wear mechanisms of oxides and delamination were observed during the lower sliding speed and higher sliding speed respectively.
- The micro-cracks were observed in the worn surfaces which were perpendicular to the sliding direction but these micro-cracks were very less in the 2%.wt. yttrium oxide reinforced composite.
- The change of specific wear rate was more at the lower sliding distances as compared to the higher sliding distances.
- The frictional coefficient were observed as low when the sling velocity at 0.9 m/s.

REFERENCES

1. *Aadarsh Mishra, 'Analysis Of Friction and Wear of Titanium Alloys' International Journal of Mechanical Engineering & Robotics, (2014), Vol. 3, No. 3, pp. 570-573.*
2. *Cotton JD, Briggs RD, Boyer RR, 'State of the art in beta titanium alloys for airframe applications', Journal of Occupational Medicine, (2015), Vol. 67, pp.1281–1303.*
3. *Bychkov A. S, FedirkoV. N., 'Analysis of the in-service failures of metal structures of the aircraft equipment'. Materials Science, (2016), Vol.52, pp.9–16.*
4. *Reddy, A. C. Low And High Temperature Micromechanical Behavior Of Bn/3003 Aluminum Alloy Nanocomposites.*

5. *Jun Qu, Peter JB, Thomas RW, 'Friction and wear of titanium alloys sliding against metal, polymer, and ceramic counterfaces' Wear (2005), Vol. 258, pp.1348–1356.*

6. *Zhang QY, Zhou Y, Wang L, Cui XH, Wang SQ, 'Investigation on tribo-layers and their function of a titanium alloy during dry sliding', Tribology International, (2016), Vol. 94, pp.541–549.*

7. *Jeong Hyeon -Gyeong, Lee Yongtai, Lee Dong-Geun, 'Effects of pre-heat conditions on diffusion hardening of pure titanium by vacuum rapid nitriding', Surface Coating Technology, (2017), Vol. 326, pp.395–401.*

8. *Bazaria, B., & Kumar, P. (2018). Optimization of spray drying parameters for beetroot juice powder using response surface methodology (RSM). Journal of the Saudi society of agricultural sciences, 17(4), 408-415.*

9. *Pohrelyuka I. M, Sheykinb S.E, Padgurskasc J, Lavrys S.M, 'Wear resistance of two-phase titanium alloy after deformation-diffusion treatment', Tribology International, (2018), Vol. 127, pp. 404–411.*

10. *Frary, M.;Abkowitz, S.;Abkowitz,S.M., Dunand, D.C. 'Microstructure and mechanical properties of Ti/W and Ti–6Al–4V/W composites fabricated by powder-metallurgy'. Materials Science and Engineering A, (2003), Vol. 344 (1-2), pp.103–112.*

11. *Trevisiol. C, A. Jourani, S. Bouvier 'Effect of martensite volume fraction and abrasive particles size on friction and wear behaviour of a low alloy steel', Tribology International, (2017), Vol.113, pp. 411-425.*

12. *Christaras, B., Moropoulou, A., Chatziangelou, M., Dimitraki, L., & Devlioti, K. (2016). Comparative surface damage determination at a Jewish grave using two different mobile ultrasonic velocity devices. Bulletin of the Geological Society of Greece, 50(3), 1626-1632.*

13. *Dube N.M, Hutchings I.M., 'Influence of particle fracture in the high-stress and low-stress abrasive wear of steel', Wear, (1999), Vol.233–235 pp. 246-256*

14. *Jourani A, Hagège B, Bouvier B, Bigerelle M, Zahouani H, 'Influence of abrasive grain geometry on friction coefficient and wear rate in belt finishing', Tribology International, (2013),Vol.59, pp. 30-37.*

15. *Jourani A, Bouvier S, 'Friction and wear mechanisms of 316L stainless steel in dry sliding contact: effect of abrasive particle size', Tribology Transactions, (2015), Vol. 58 (1) , pp. 131-139.*

16. *Gaurav Agarwal, Amar Patnaik,, Rajesh Kumar Sharma, 'Parametric Optimization and Three-Body Abrasive Wear Behavior of Sic Filled Chopped Glass Fiber Reinforced Epoxy Composites', International Journal of Composite Materials, (2013),Vol. 3(2), pp. 32-38.*

17. *Khruschov M.M, 'Principles of abrasive wear', Wear, (1974), Vol.28, pp.69–88.*

18. *Garrison Jr W. M., 'Abrasive wear resistance: the effects of ploughing and the removal of ploughed materials', Wear, (1987), Vol.114, pp.239–247.*

19. *Nam P. Suh, 'Tribophysics', Englewood Cliffs, NJ: Prentice-Hall, 1986.*

20. *Ramaswamy, R, Selvam, B, Marimuthu, P, Elango, N, 'Investigation of Densification Behaviour on Yttrium Oxide Reinforced Ti-6Al-4V Nano-composite Through Powder Metallurgy', International Journal of Mechanical and Production Engineering Research and Development, (2018), Vol.8 (2), pp.433-442.*

21. *Cao, T. B., & Kedziora, S. (2017). New methodology for designing direct-laser-sintered motorcycle frame based on combination of topology optimization and lattice implementation.*

22. *Æ. K. M, Patel, V. V, 'Processing and properties of titanium – titanium boride (TiB w) matrix composites — a review', (2007), pp. 2037–2047.*

23. *Zadra M and Girardini L, 'High-performance, low-cost titanium metal matrix composites', Material Science and Enineering. A, (2014), Vol. 608, pp. 155–163.*

24. *Selvam, B, Marimuthu, P, Narayanasamy, R, Anandakrishnan, V, Tun, S, Gupta, M, Kamaraj, M, 'Dry sliding wear behaviour of zinc oxide reinforced magnesium matrix nano-composites', Materials and Design (Elsevier), (2014), Vol. 58, pp.475–481.*

25. *Qu. J., Blau, P.J., Watkins, T.R., Cavin, O.B. and Kulkarni, N.S., 'Friction and Wear of Titanium Alloy Sliding against Metal, Polymer, Ceramic counterfaces', Wear, (2005), Vol.258, pp.1348-1356.*